NUCLEONICA: Decay Engine++

J. MAGILL

Nucleonica GmbH
c/o European Commission,
Hermann-von-Helmholtz Platz 1
76344 Eggenstein-Leopoldshafen,
Germany

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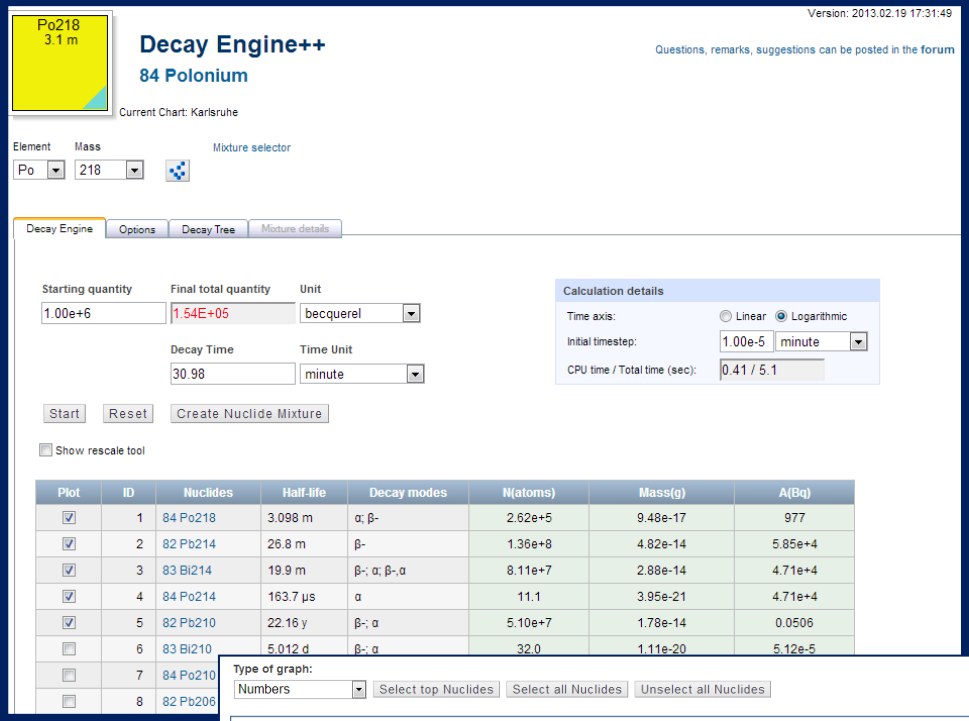
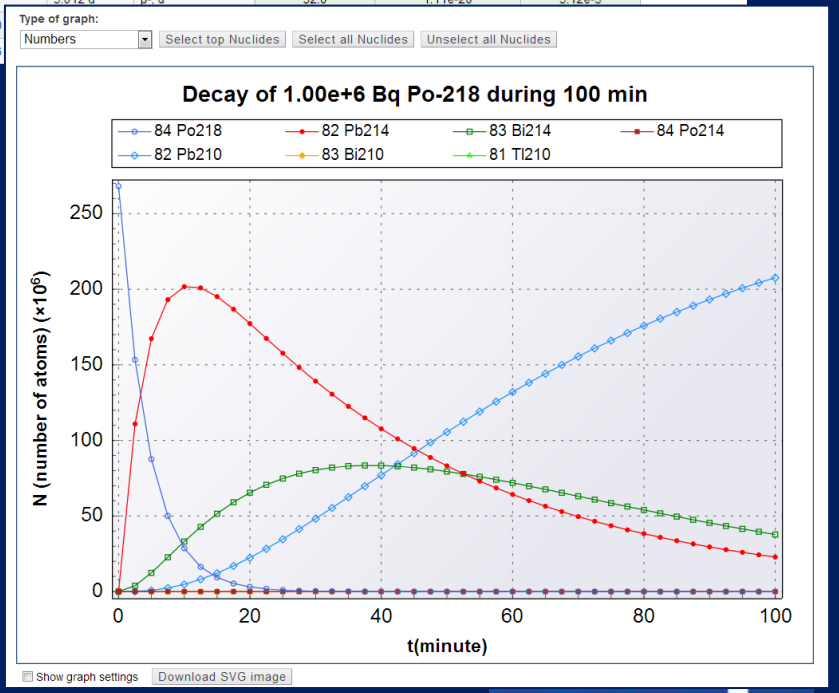
Decay Engine++

- Some theory
- Launching Decay Engine++
- Performing calculation with default settings
- Exploring calculation results
- Selecting options
- Plotting results





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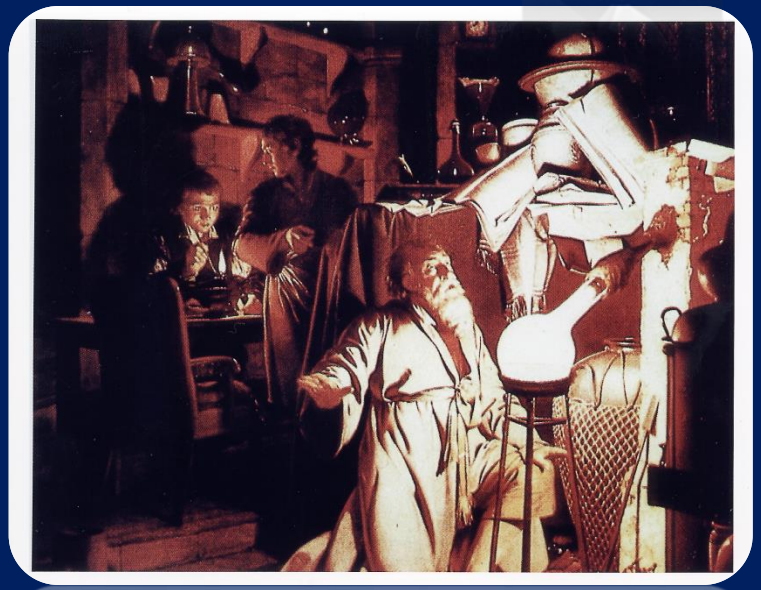
Modern Alchemy: Discovery of transmutation, (Soddy 1901)

In 1901, twenty-four year-old chemist Frederick Soddy and Ernest Rutherford were attempting to identify a mysterious gas that wafted from samples of radioactive thorium oxide. They suspected that this gas—they called it an "emanation"—held a key to the recently discovered phenomenon of radioactivity. Soddy had passed the puzzling gas over a series of powerful chemical reagents, heated white-hot. When no reactions took place, he came to a startling realization. As he told his biographer many years later….

´I remember quite well standing there transfixed as though stunned by the colossal import of the thing and blurting out- or so it seemed at the time: "Rutherford, this is transmutation: the thorium is disintegrating and transmuting itself into argon gas". Rutherford's reply was typically aware of more practical implications,"For Mike's sake, Soddy, don't call it *transmutation*. They'll have our our heads off as alchemists"`

*quoted in *Pioneer*, pp 83-84

Frederic Soddy



Joseph Wright (1734-1797)

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Simple radioactive decay..

Basic equation first identified by Rutherford

$$dQ/dt = -kQ \qquad (1)$$

Q is the number of atoms, k is the decay constant (probability per unit time that a nucleus will decay):

$$k = \ln 2 / \tau$$

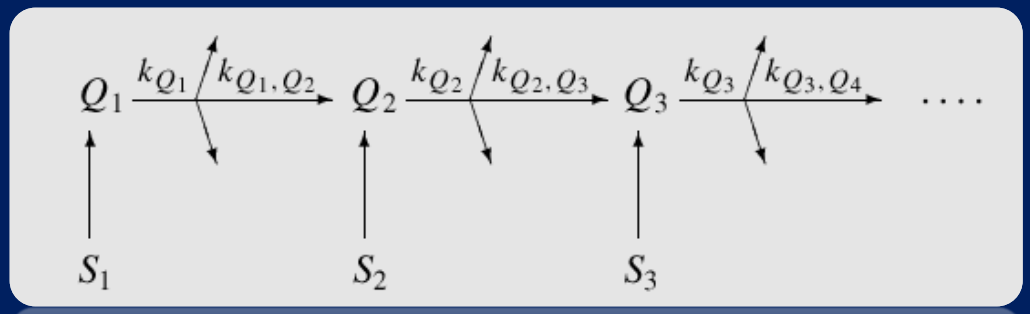
where τ is the half-live. Solution of Eq.1...

$$Q(t) = Q(0)\, e^{-kt} \quad \text{or} \quad Q(t) = Q(0)\, 2^{-t/\tau}$$

Activity..

$$A(t) = k\, Q(t)$$

Successive radioactive decay with branching and source terms



The differential equations governing the above processes:

$$\mathrm{d}Q_1/\mathrm{d}t = S_1 - k_{Q_1} \cdot Q_1 \,,$$
$$\mathrm{d}Q_2/\mathrm{d}t = S_2 + k_{Q_1,Q_2} \cdot Q_1 - k_{Q_2} \cdot Q_2 \,,$$
$$\mathrm{d}Q_i/\mathrm{d}t = S_i + k_{Q_{i-1},Q_i} \cdot Q_{i-1} - k_{Q_i} \cdot Q_i \,,$$
$$\mathrm{d}Q_n/\mathrm{d}t = S_n + k_{Q_{n-1},Q_n} \cdot Q_{n-1} - k_{Q_n} \cdot Q_i \,,$$


H. Bateman

Mr Bateman, Solution of a system of differential equations, etc. 423

The solution of a system of differential equations occurring in the theory of radio-active transformations. By H. Bateman, M.A., Trinity College.

[*Read* 21 February 1910.]

1. It has been shown by Prof. Rutherford * that the amounts of the primary substance and the different products in a given quantity of radio-active matter vary according to the system of differential equations,

$$\left.\begin{aligned} \frac{dP}{dt} &= -\lambda_1 P \\ \frac{dQ}{dt} &= \lambda_1 P - \lambda_2 Q \\ \frac{dR}{dt} &= \lambda_2 Q - \lambda_3 R \\ \frac{dS}{dt} &= \lambda_3 R - \lambda_4 T \\ &\cdots\cdots\cdots \end{aligned}\right\} \cdots\cdots\cdots\cdots\cdots\cdots (1),$$

denote the number of atoms of the primary
ve products which are present at time t.
as worked out the various cases in which
ducts in addition to the primary substance,
ght as if the results may be extended to any
ithout much labour.
straightforward method is unsymmetrical
the results of the calculations are needed in
which are being carried on in radio-activity
ht it worth while to publish a simple and
of obtaining the required formulæ.
ce a set of auxiliary quantities $p(x)$, $q(x)$,
on a variable x and connected with the
$R(t)$, ... by the equations

$$p(x) = \int_0^\infty e^{-xt} P(t)\,dt, \quad q(x) = \int_0^\infty e^{-xt} Q(t)\,dt \cdots\cdots (2).$$

It is easily seen that

$$\int_0^\infty e^{-xt} \frac{dP}{dt}\,dt = -P(0) + x\int_0^\infty e^{-xt} P(t)\,dt \cdots\cdots (3),$$
$$= -P_0 + xp,$$

* Radio-activity, 2nd edition, p. 382.

Exact solution:

$$Q_{\mathrm{n}}(t) = \sum_{i=1}^{i=n} \left[\left(\prod_{j=1}^{j=n-1} k_{j,j+1} \right) \times \sum_{j=i}^{j=n} \left(\frac{Q_i\,(0)\,\mathrm{e}^{-k_j t}}{\prod_{\substack{p=i \\ p\neq j}}^{n} \left(k_p - k_j\right)} + \frac{S_i\left(1 - \mathrm{e}^{-k_j t}\right)}{k_j \prod_{\substack{p=i \\ p\neq j}}^{n} \left(k_p - k_j\right)} \right) \right]$$

For $S_i = 0$:

$$Q_{\mathrm{n}}\,(t) = \prod_{j=1}^{j=n-1} k_{j,j+1} \sum_{j=i}^{j=n} \frac{Q_i\,(0)\,\mathrm{e}^{-k_j t}}{\prod_{\substack{p=i \\ p\neq j}}^{n} \left(k_p - k_j\right)}$$

First few terms...

$$Q_1 = Q_1\,(0)\,\mathrm{e}^{-k_1 t}$$

$$Q_2 = k_{1,2} \left\{ \frac{Q_1\,(0)\,\mathrm{e}^{-k_1 t}}{k_2 - k_1} + \frac{Q_1\,(0)\,\mathrm{e}^{-k_2 t}}{k_1 - k_2} \right\}$$

$$Q_3 = k_{1,2} k_{2,3} \left\{ \frac{Q_1\,(0)\,e^{-k_1 t}}{(k_2 - k_1)\,(k_3 - k_1)} + \frac{Q_1\,(0)\,\mathrm{e}^{-k_2 t}}{(k_1 - k_2)\,(k_3 - k_2)} + \frac{Q_1\,(0)\,\mathrm{e}^{-k_3 t}}{(k_1 - k_3)\,(k_2 - k_3)} \right\}$$

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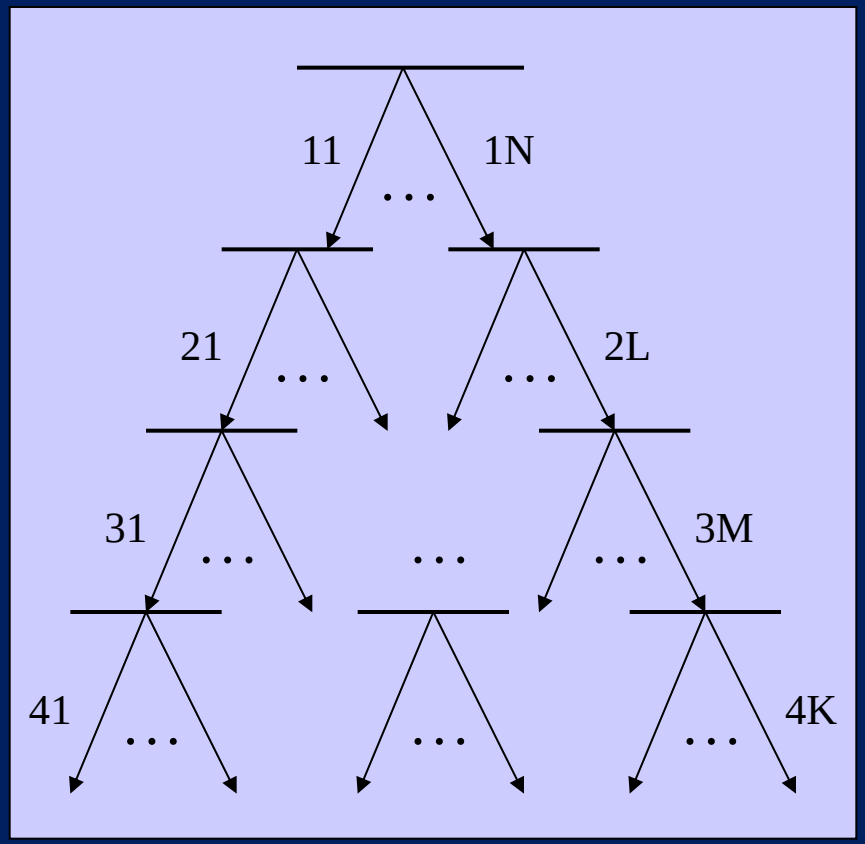
Decay Tree



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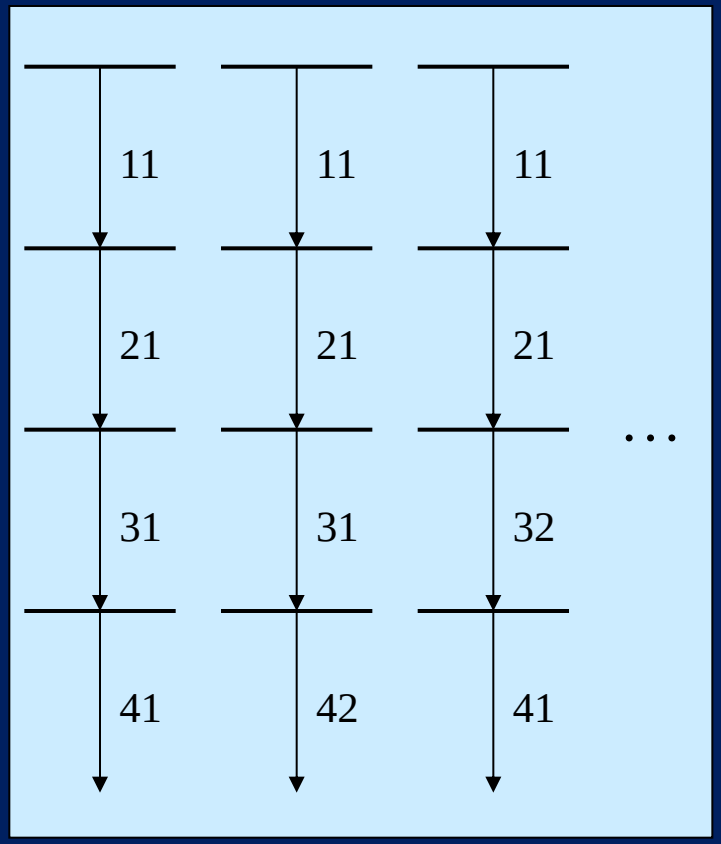
Linear Chains



$$Prod_1 = BR_{11}BR_{21}BR_{31}BR_{41}$$

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Applications
- Nuclide Explorer
- Mass Activity Calculator
- Mass Activity Converter
- Decay Engine
- Decay Engine++
- Dosimetry and Shielding
- Range and Stopping Power
- In Silico Dosimetry
- webKORIGEN
- Decay Engine for Large Nuclide Sets
- Universal Nuclide Chart
- e-Ship: radiological transport assistant
- Transport and Packaging
- Nuclide Mixtures
- Nucleonica Scripting
- Radiological Dispersion Module
- Gamma Spectrum Generator
- Gamma Spectrum Generator Pro
- Virtual Cloud Chamber
- Geant4 Dosimetry
- Cambio file converter
- WESPA
- WESPA2
- Gamma Library
- webGraph

dge | My Preferences | Networking | Nuclear Science | Help | New Browser | Logout

hart: Karlsruhe

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Search

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nucleonica [wiki]

Application Centre
- Mass Activity Calculator
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- Radiological Dispersion Module
- Gamma Spectrum Generator
- Gamma Spectrum Generator Pro
- Virtual Cloud Chamber
- Geant4 Dosimetry
- easy Monte Carlo
- Cambio file Converter

Welcome, Joseph

My Settings | Administration

Networking

To launch the Decay Engine

click on Decay Engine in the Application Center list.....

or

choose Decay Engine from the Applications dropdown list….

Pu241 with daughters

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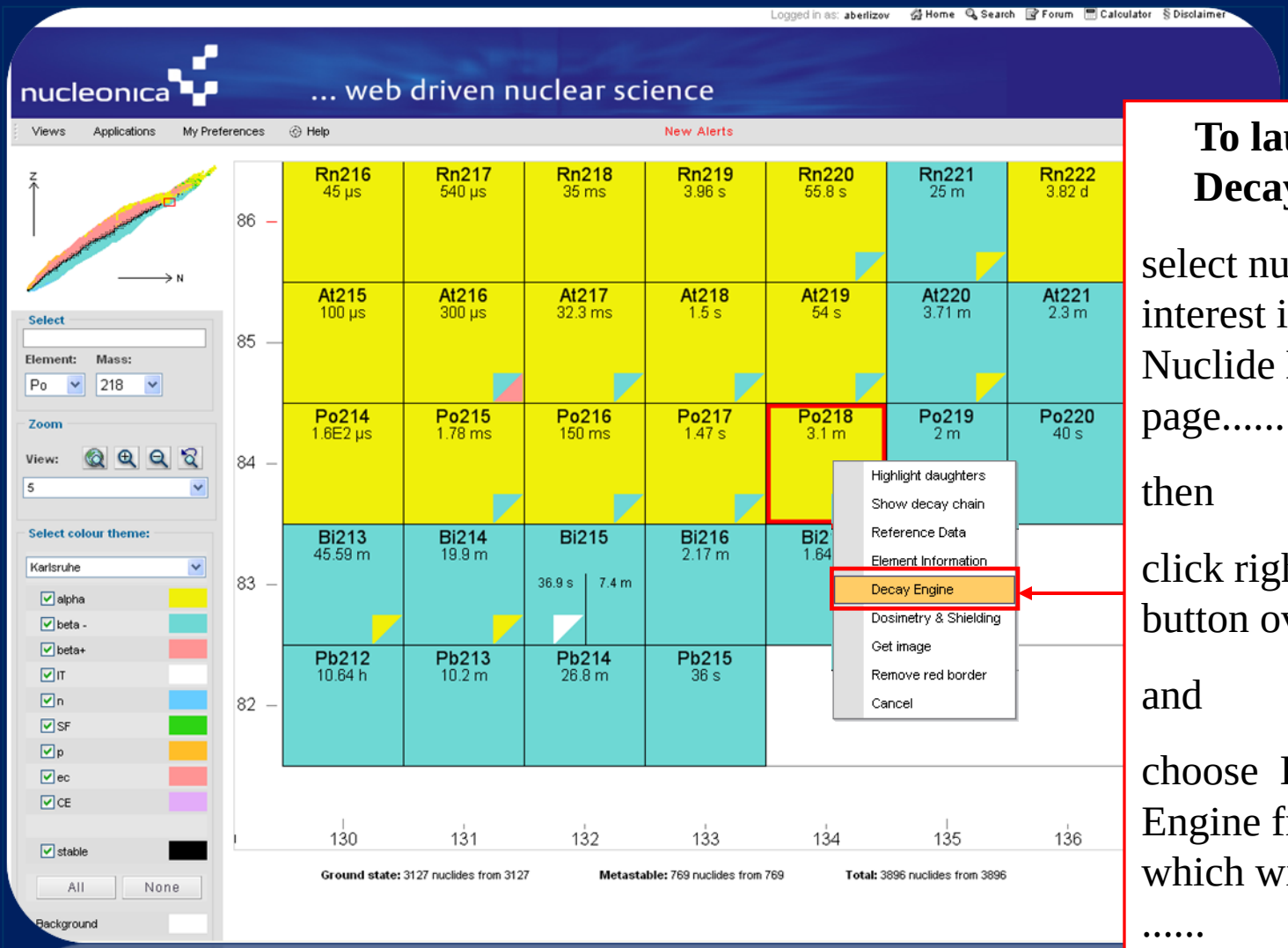
Internet Explorer only!



To launch the Decay Engine

select nuclide of interest in the Nuclide Explorer page.....

then

click right mouse button over it .....

and

choose Decay Engine from the list, which will appear .....

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Typical calculation…

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Applications | Data | Knowledge | My Preferences | Print

Po218
3.1 m

Decay Engine++

84 Polonium

Current Chart: Karlsruhe

Element: Po | Mass: 218 | Mixture selector

Decay Engine | Options | Decay Tree | Mixture details

Starting quantity: 1.00e+6
Final total quantity: ???
Unit: becquerel
Decay Time: 30.98
Time Unit: minute

Start | Reset

Start a calculation using default value…

Version: 2013.0

Questions, remarks, suggestions can be poste

Current Chart: Karlsruhe

Element: Po | Mass: 218 | Mixture selector

Decay Engine | Options | Decay Tree | Mixture details

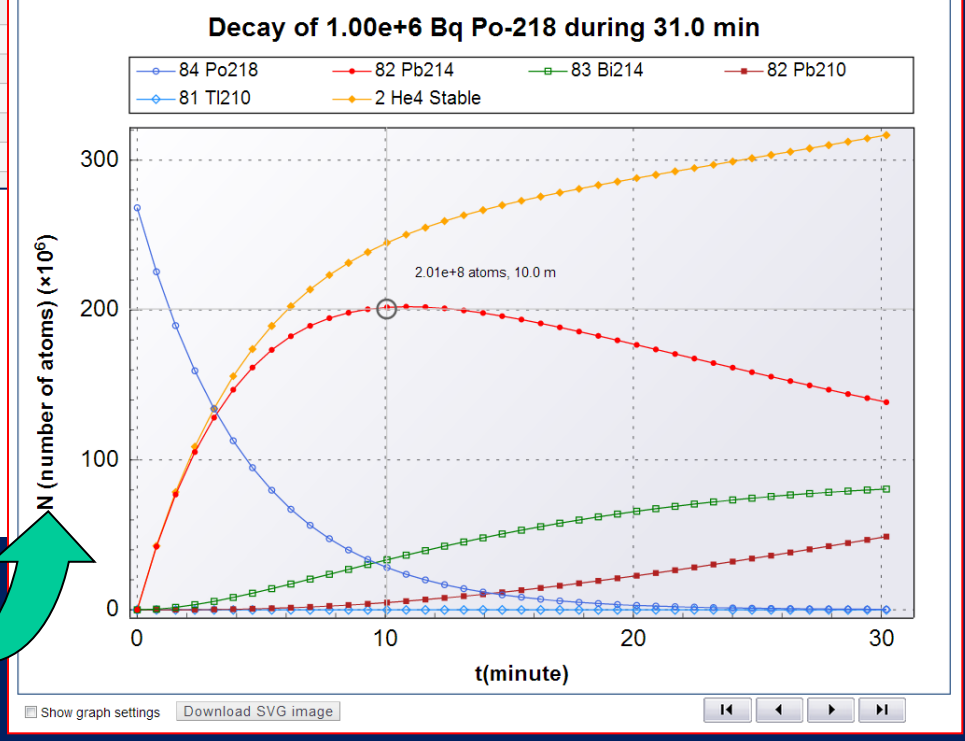
Starting quantity: 1.00e+6
Final total quantity: 1.54E+05
Unit: becquerel
Decay Time: 30.98
Time Unit: minute

Start | Reset

Calculation details
Time axis: Linear / Logarithmic
Initial timestep: 0 minute
CPU time / Total time (sec): 0.30 / 5.1

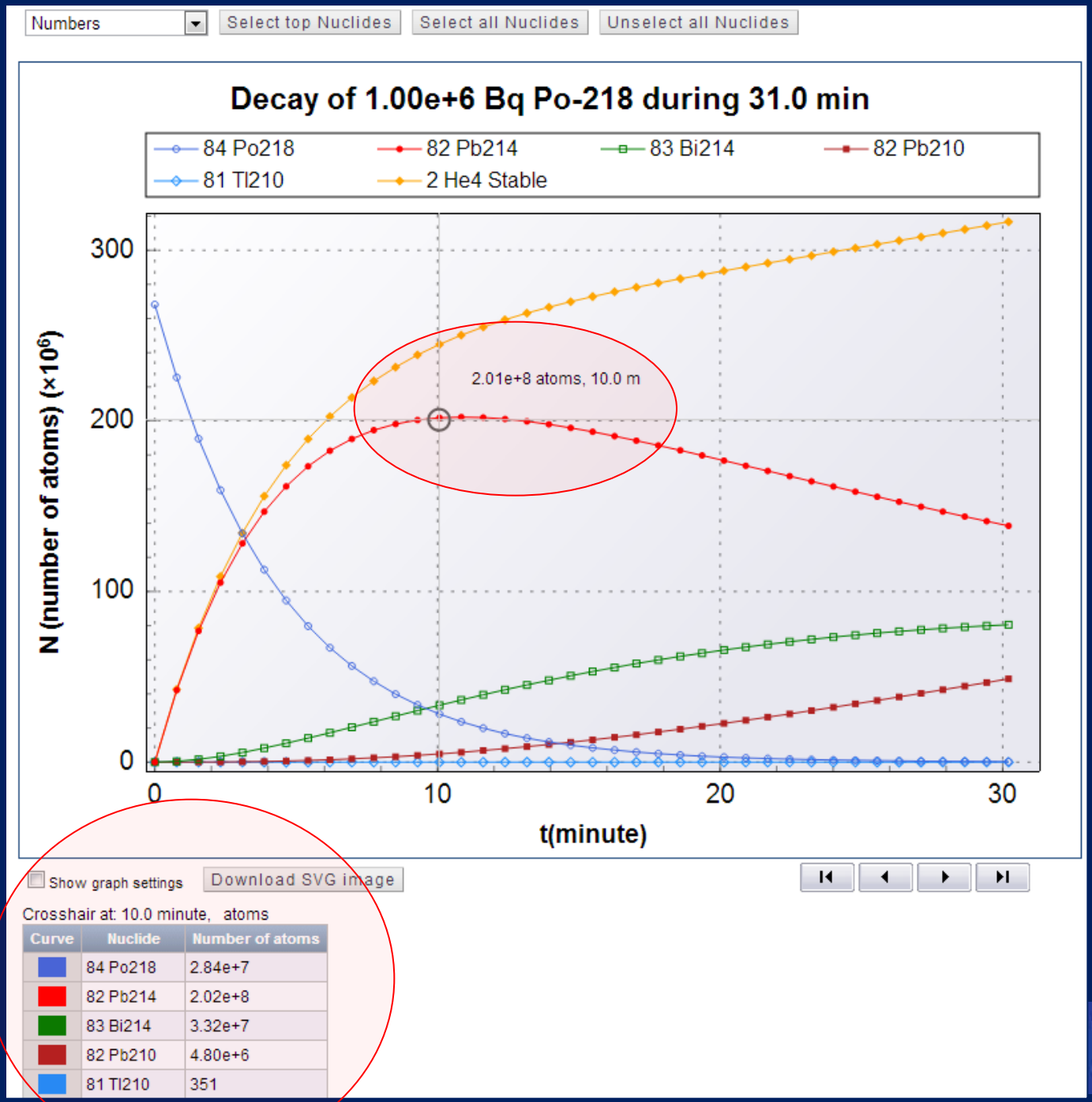
Type of graph: Numbers | Select top Nuclides | Select all Nuclides | Unselect all Nuclides

Plot



Show graph settings | Download SVG image

Slider control for easy reading graph values…

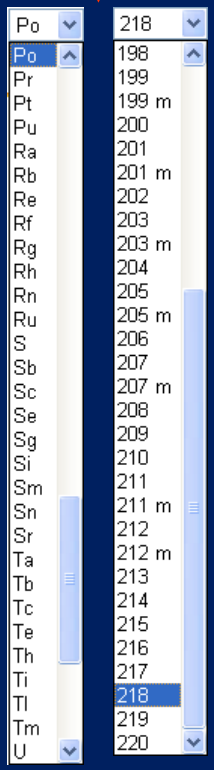


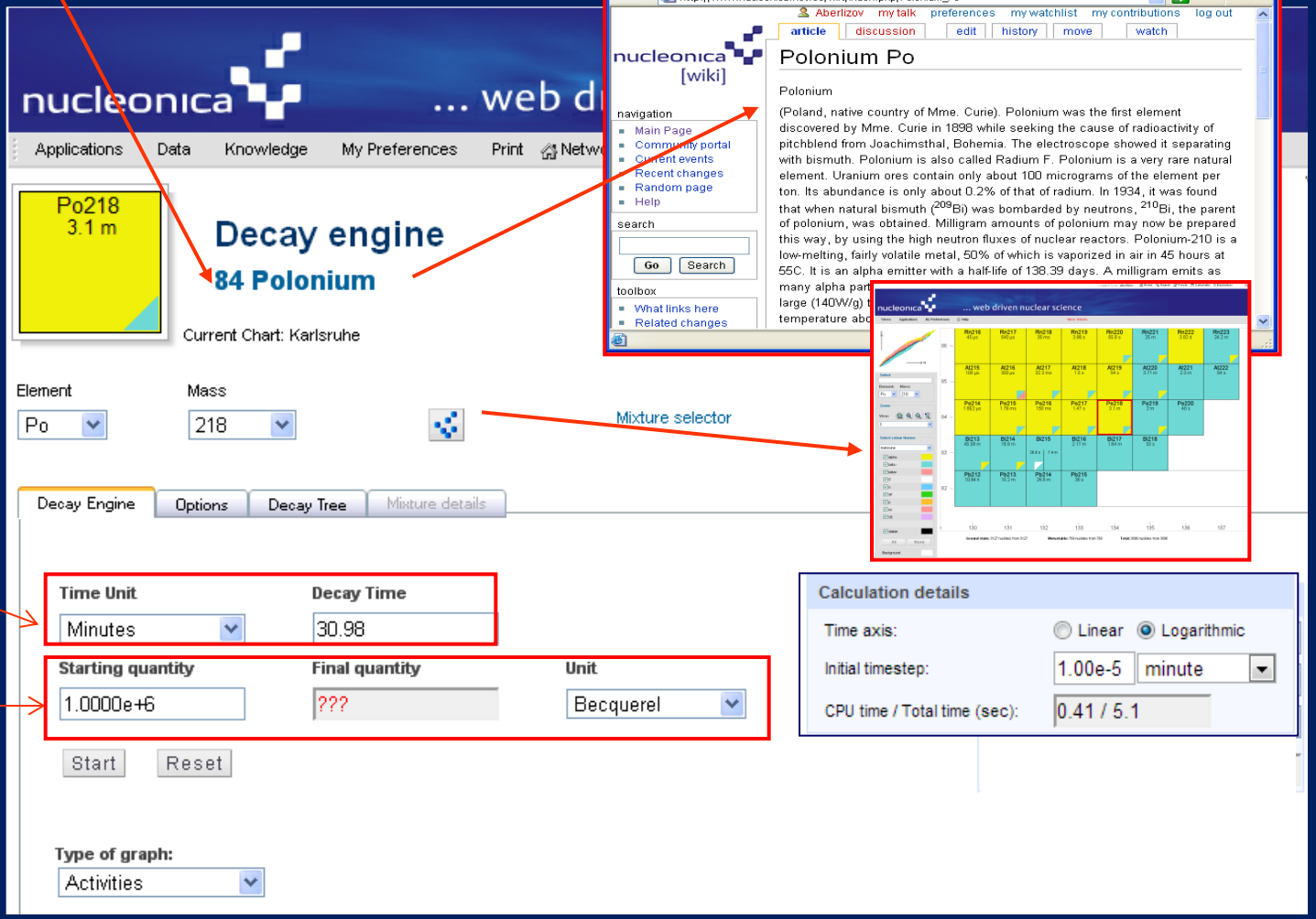
Element Info in Nucleonica wiki

Nuclide selection tools

Set time

Set quantity





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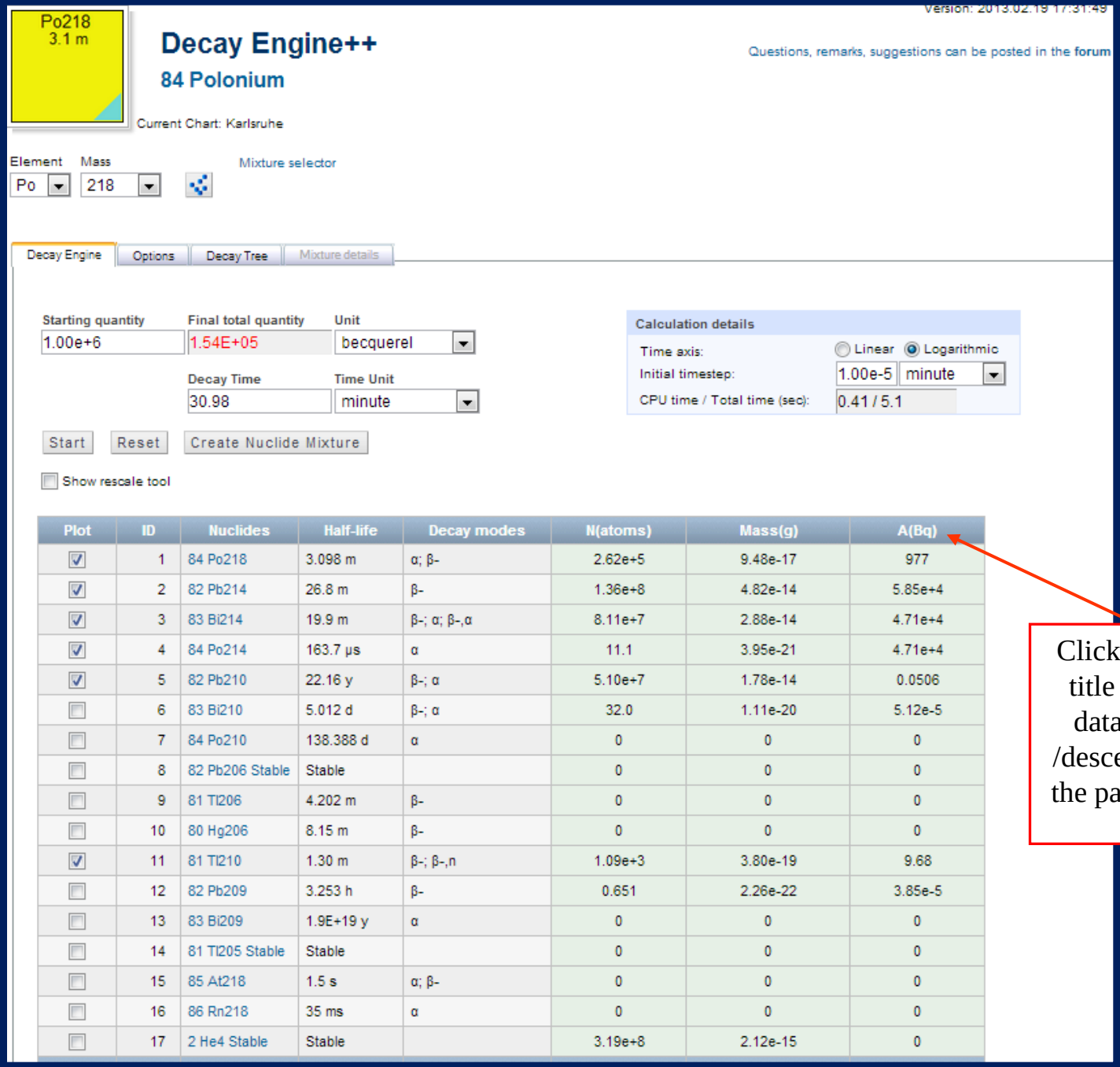

Plot	ID	Nuclides	Half-life	Decay modes	N(atoms)	Mass(g)	A(Bq)
☑	1	84 Po218	3.098 m	α; β-	2.62e+5	9.48e-17	977
☑	2	82 Pb214	26.8 m	β-	1.36e+8	4.82e-14	5.85e+4
☑	3	83 Bi214	19.9 m	β-; α; β-,α	8.11e+7	2.88e-14	4.71e+4
☑	4	84 Po214	163.7 µs	α	11.1	3.95e-21	4.71e+4
☑	5	82 Pb210	22.16 y	β-; α	5.10e+7	1.78e-14	0.0506
☐	6	83 Bi210	5.012 d	β-; α	32.0	1.11e-20	5.12e-5
☐	7	84 Po210	138.388 d	α	0	0	0
☐	8	82 Pb206 Stable	Stable		0	0	0
☐	9	81 Tl206	4.202 m	β-	0	0	0
☐	10	80 Hg206	8.15 m	β-	0	0	0
☑	11	81 Tl210	1.30 m	β-; β-,n	1.09e+3	3.80e-19	9.68
☐	12	82 Pb209	3.253 h	β-	0.651	2.26e-22	3.85e-5
☐	13	83 Bi209	1.9E+19 y	α	0	0	0
☐	14	81 Tl205 Stable	Stable		0	0	0
☐	15	85 At218	1.5 s	α; β-	0	0	0
☐	16	86 Rn218	35 ms	α	0	0	0
☐	17	2 He4 Stable	Stable		3.19e+8	2.12e-15	0

Click on the column title to arrange the data in ascending /descending order on the parameter chosen

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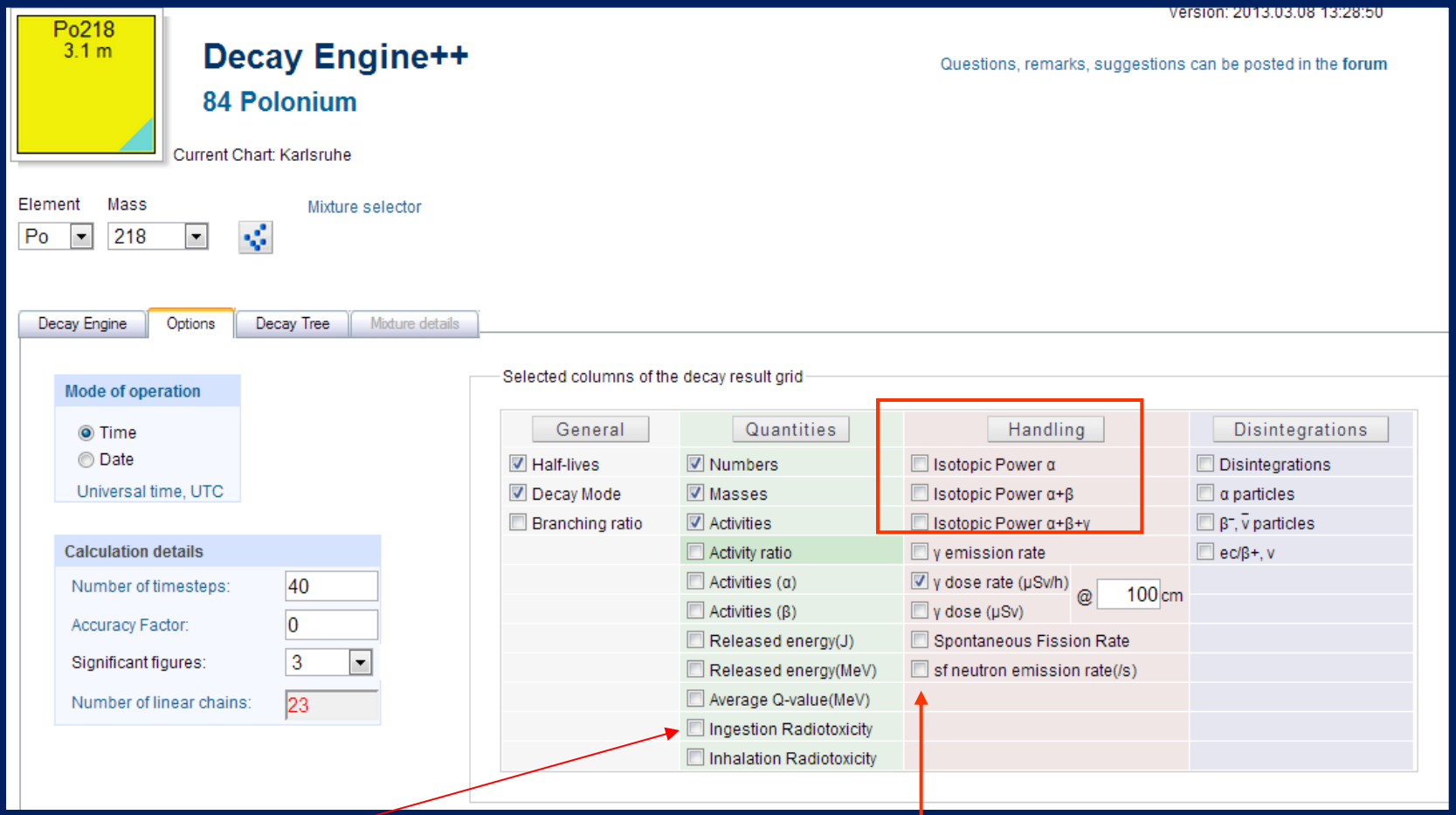

Radiotoxicity (Sv) = Activity · *e*(50), where e(50) - effective dose coefficient, which accounts for radiation and tissue weighting factors, metabolic and biokinetic information

the heat generated per unit time by the decay radiations (W)

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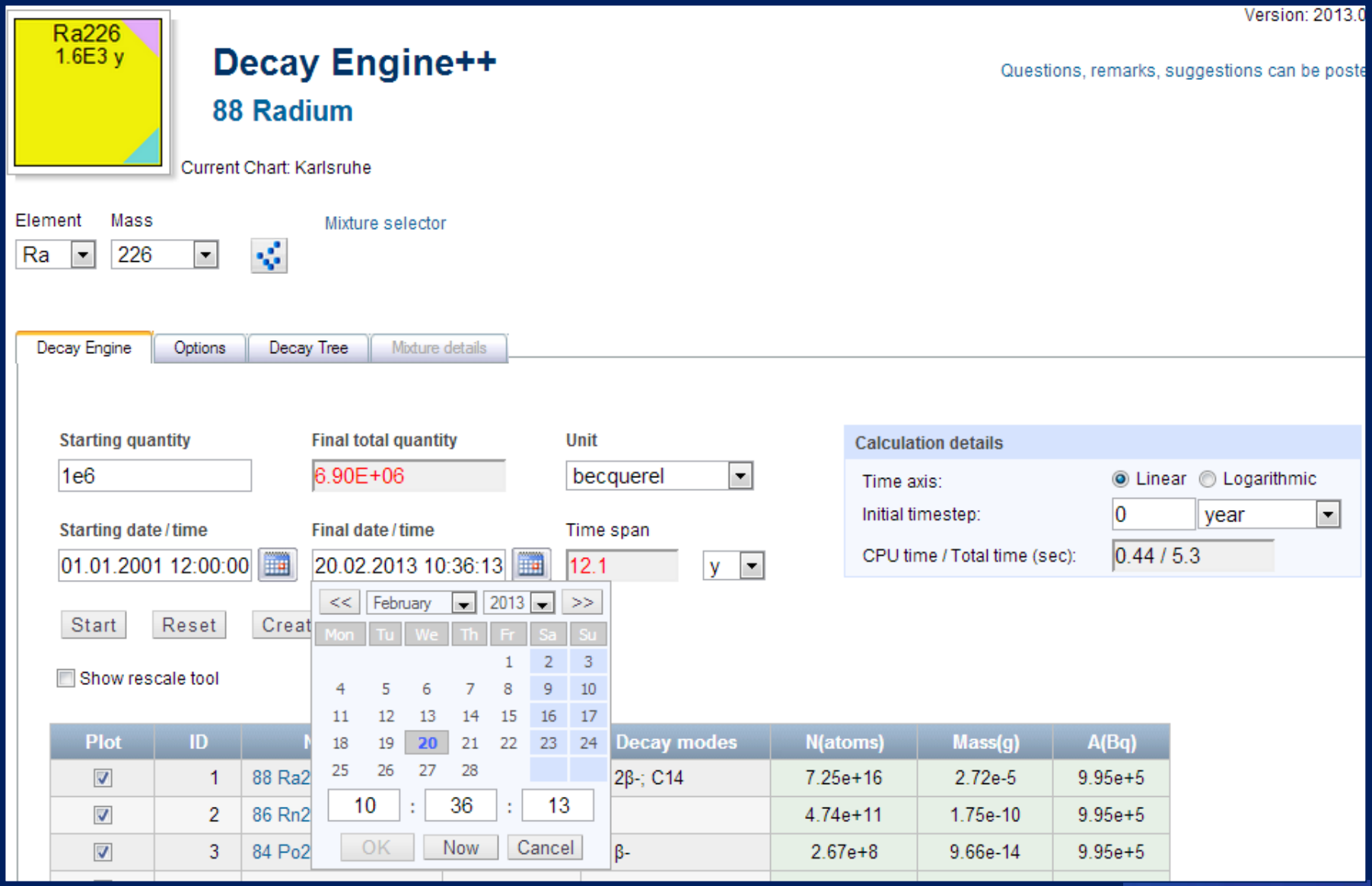
Date mode:



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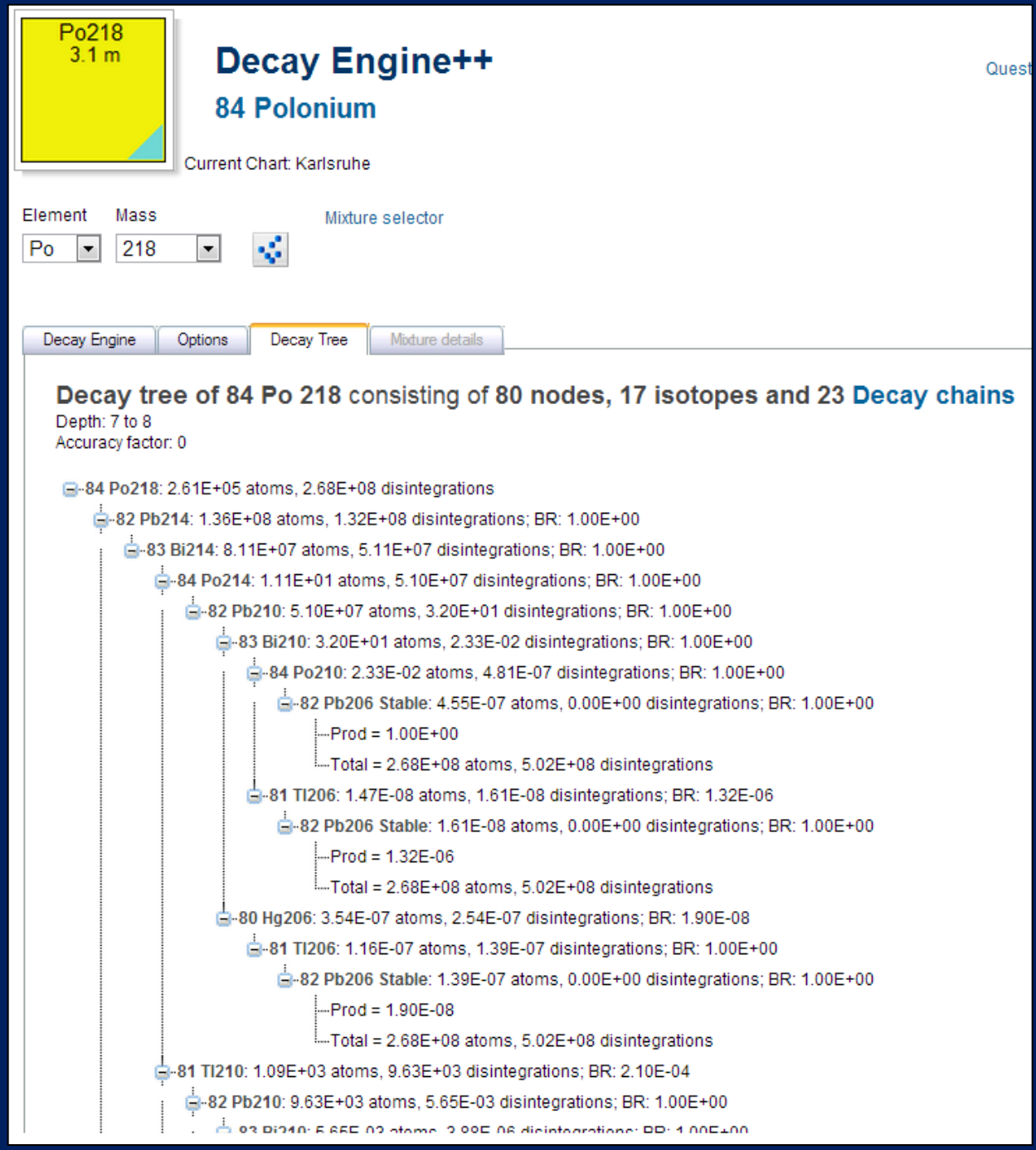
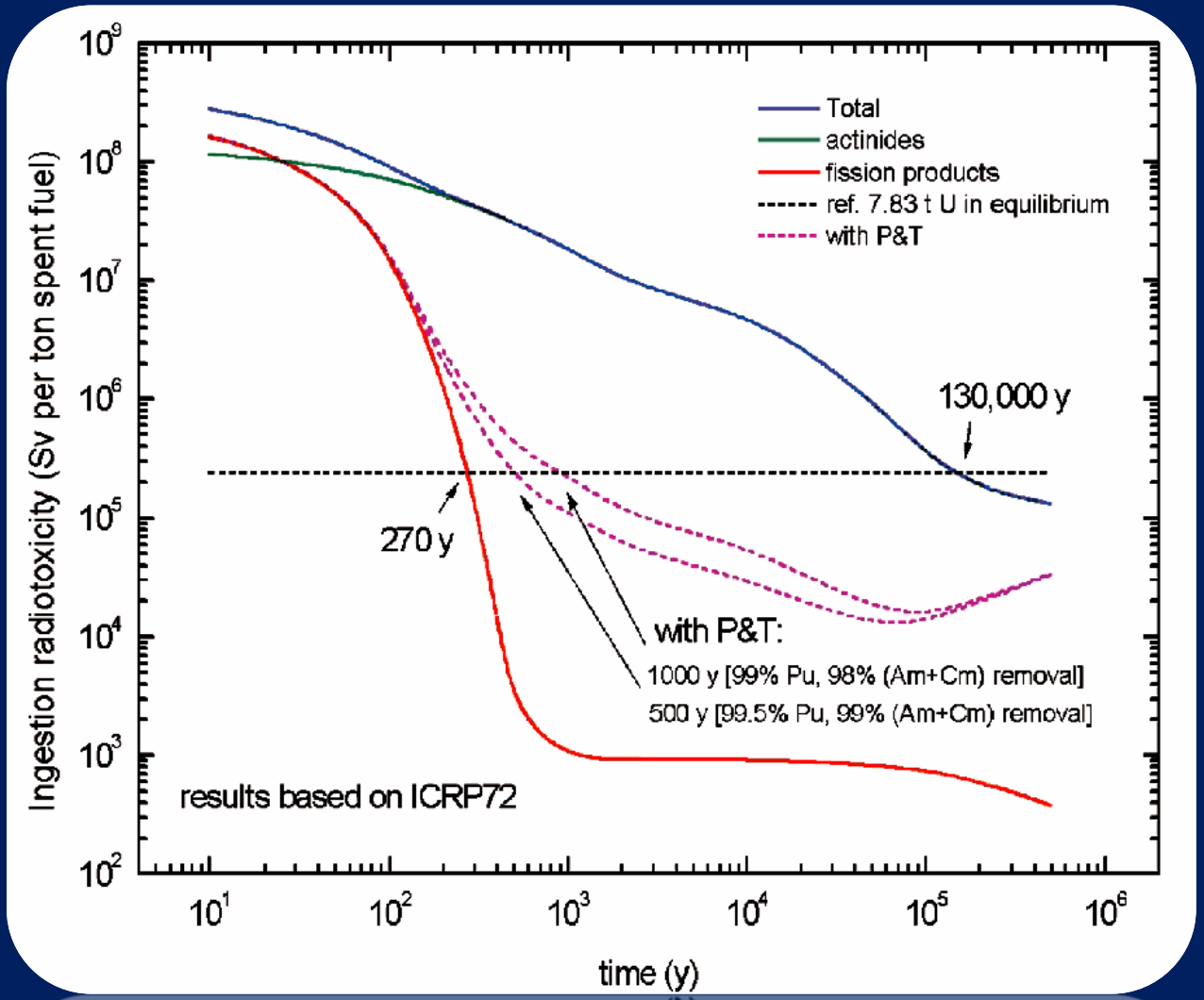
Decay Tree tab showing details of decay process – linear chains, etc.




Total
actinides
fission products
ref. 7.83 t U in equilibrium
with P&T
130,000 y
270 y
with P&T:
1000 y [99% Pu, 98% (Am+Cm) removal]
500 y [99.5% Pu, 99% (Am+Cm) removal]
results based on ICRP72
Ingestion radiotoxicity (Sv per ton spent fuel)
time (y)

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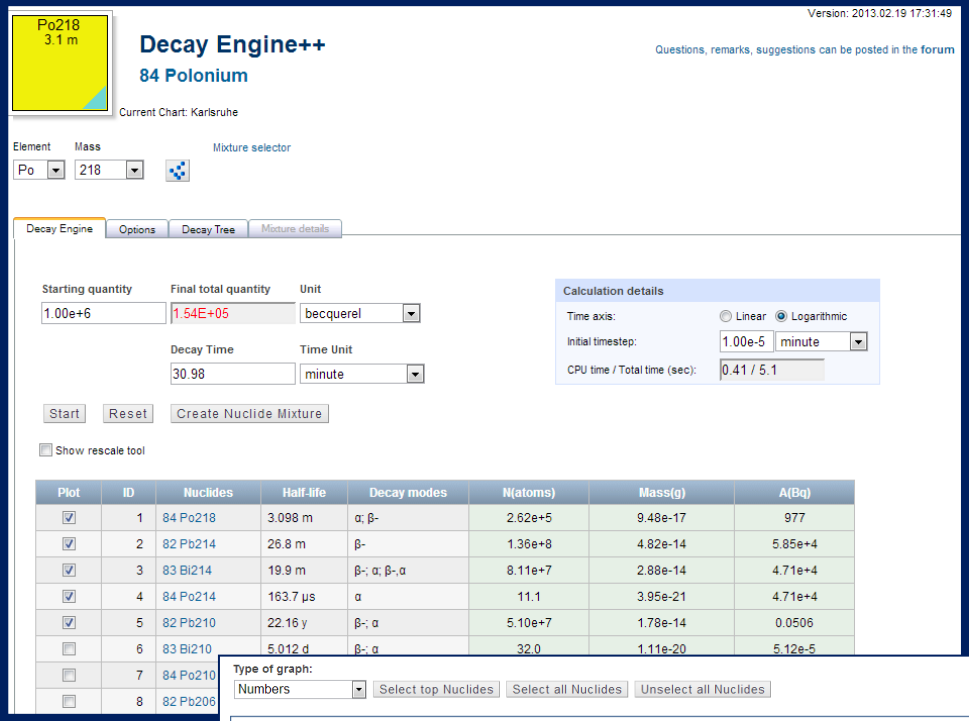

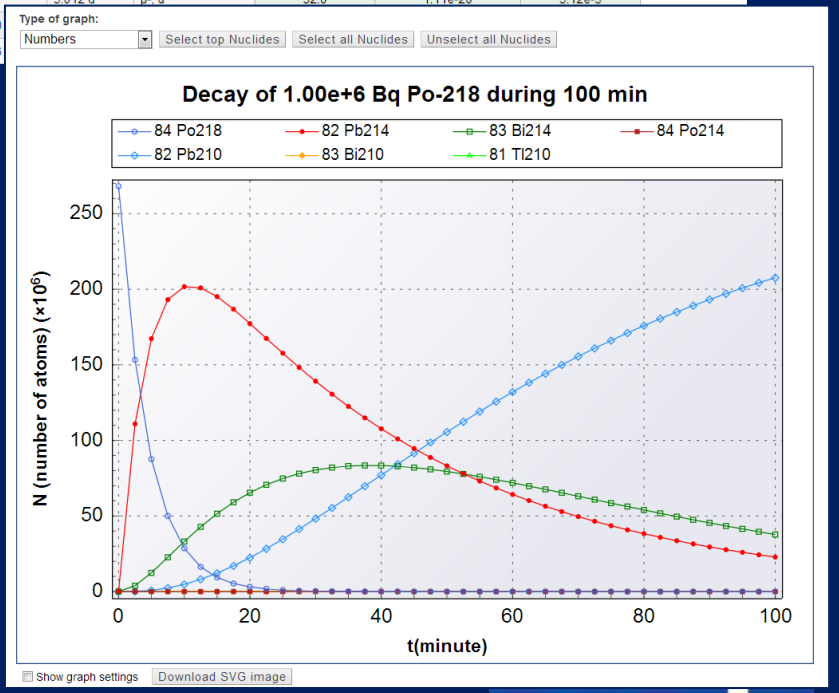

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Thanks!

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Exercises - Decay Engine++

1. At t=0 there are 10 Ci of Sr-90. What will be the activity of Y-90 after 5 years? Ans. 8.87 Ci

2. What is the time required for the activity of Na-24 to diminish to 1% of its initial value? Ans. 4.14 d

3. What initial mass of F-18 is required in order that there are 3 mg remaining after 16 hours?(1.3g)

4. Calculate the activity of a Tl-204 source today that was calibrated at 1 µCi on Sept. 3, 1993. (30.2 nCi, 22 Oct. 2012)

5. What is the activity of a Rn-222 sample in an ore sample containing 3g uranium (Rn-222 is produced by U-238) (37 kBq at 1e6 years)

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